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Coal Refuse Piles, Abandoned Mines and Outcrops, State of the Art

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16. ABSTRACT

This report describes a study of atmospheric emissions from coal refuse piles, abandoned mines, and outcrops. The potential environmental effect of the source was evaluated using source severity (defined as the ratio of the maximum time-averaged ground level concentration of an emission to a hazard factor). A representative burning coal pile/impoundment is defined as one with a volume of 1.7×10^6 m^3 and an average *in-situ* dry density of 1.5 metric tons/m^3, with about 21% of it burning. Burning of coal piles, impoundments, abandoned mines, and outcrops results in emissions of various pyrolysis and combustion products such as particulates, nitrogen oxides, sulfur oxides, carbon monoxide, hydrogen sulfide, ammonia, polycyclic organic materials (POM), and hydrocarbons, including benzene, toluene, and xylene. Trace elements such as arsenic, boron, and mercury are also emitted. Emissions from fires in coal refuse piles, abandoned mines, and outcrops contribute 0.001% of the particulates, 0.16% of the nitrogen oxides, 0.14% of the sulfur oxides, 0.14% of the hydrocarbons, and 4.9% of the carbon monoxide emitted nationally.

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State of the Art

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report contains an assessment of air emissions from coal refuse piles, abandoned mines and outcrops. This study was conducted to provide a better understanding of the distribution and characteristics of emissions from this source type. Further information on this subject may be obtained from the Extraction Technology Branch, Resource Extraction and Handling Division.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

PREFACE

The Industrial Environmental Research Laboratory (IERL) of the U.S. Environmental Protection Agency (EPA) has the responsibility for insuring that pollution control technology is available for stationary sources to meet the requirements of the Clean Air Act, the Federal Water Pollution Control Act, and solid waste legislation. If control technology is unavailable, inadequate, or uneconomical, then financial support is provided for the development of the needed control techniques for industrial and extractive process industries. Approaches considered include process modifications, feedstock modifications, add-on control devices, and complete process substitution. The scale of the control technology programs ranges from bench- to full-scale demonstration plants.

IERL has the responsibility for developing control technology for a large number of operations (more than 500) in the chemical and related industries. As in any technical program, the first step is to identify the unsolved problems. Each of the industries is to be examined in detail to determine if there is sufficient potential environmental risk to justify the development of control technology by IERL.

Monsanto Research Corporation (MRC) has contracted with EPA to investigate the environmental impact of various industries that represent sources of pollutants in accordance with EPA's responsibility, as outlined above. Dr. Robert C. Binning serves as MRC Program Manager in this overall program, entitled "Source Assessment," which includes the investigation of sources in each of four categories: combustion, organic materials, inorganic materials, and open sources. Dr. Dale A. Denny of the Industrial Processes Division at Research Triangle Park serves as EPA Project Officer for this series. Reports prepared in this program are of two types: Source Assessment Documents and State-of-the-Art Reports.

Source Assessment Documents contain data on pollutants from specific industries. Such data are gathered from the literature, government agencies, and cooperating companies. Sampling and analysis are also performed by the contractor when the available information does not adequately characterize the source pollutants. These documents contain all of the information necessary for IERL to decide whether emissions reduction is necessary.

State-of-the-Art Reports include data on pollutants from specific industries which are also gathered from the literature, government agencies and cooperating companies. However, no extensive sampling is conducted by the contractor for such industries. Sources in this category are considered by EPA to be of insufficient priority to warrant complete assessment for control technology decision-making. Therefore, results from such studies are published as State-of-the-Art Reports for potential utility by the government, industry, and others having specific needs and interests.

This State-of-the-Art Report contains data on air emissions from coal refuse piles, abandoned mines and outcrops. This project was initiated by the Chemical Processes Branch of the Industrial Processes Division at Research Triangle Park. The project was transferred to and completed by the Resources Extraction and Handling Division, IERL-Cincinnati, where Mr. John F. Martin served as EPA Project Leader.

ABSTRACT

This report describes a study of air pollutants emitted from coal refuse piles, abandoned mines, and outcrops. The potential environmental effect of the source was evaluated using source severity (defined as the ratio of the maximum time-averaged ground level concentration of an emission to a hazard factor).

Spontaneous combustion of coal results in the burning of coal refuse piles, impoundments, abandoned mines, and outcrops. There are 250 x 10^6 metric tons of burning refuse material. The amounts of refuse material in burning impoundments and of coal burning in abandoned mines and outcrops are unknown.

A representative burning coal pile/impoundment is defined as one with a volume of 1.7 x 10^6 m^3 and an average *in situ* dry density of 1.5 metric tons/m^3, with about 21% of it burning. Burning of coal piles, impoundments, abandoned mines, and outcrops results in emissions of various pyrolysis and combustion products such as particulates, nitrogen oxides, sulfur oxides, carbon monoxide, hydrogen sulfide, ammonia, polycyclic organic materials (POM), and hydrocarbons including benzene, toluene and xylene. Trace elements such as arsenic, boron and mercury are also emitted.

Emissions from fires in coal refuse piles, abandoned mines, and outcrops contribute 0.001% of the particulates, 0.16% of the nitrogen oxides, 0.14% of the sulfur oxides, 0.14% of the hydrocarbons and 4.9% of the carbon monoxide emitted nationally. The affected population (defined as the number of persons potentially exposed to concentrations of airborne materials which result in a source severity greater than 0.1) is 1,000 persons for nitrogen oxides, 180 persons for hydrocarbons as CH_4 equivalents, 6,700 persons for hydrogen sulfide, 3,900 persons for POM and zero persons for total particulate, sulfur oxides, carbon monoxide, ammonia or mercury.

The main principle to control emissions is to cut off the source of oxygen. Control practices such as blanketing the pile with incombustible material, quenching the burning pile with water, filling underground mines with fly ash slurry, isolating the burning pile/mine/outcrop, and building fire barriers have been employed.

This report was submitted in partial fulfillment of Contract 68-02-1874 by Monsanto Research Corporation under the sponsorship of the U.S. Environmental Protection Agency. The study covers the period August 1975 to July 1977.

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ABBREVIATIONS AND SYMBOLS

D	-- representative distance downwind of the source
$D_{S = 0.1}$	-- distance downwind of the source where the severity equals 0.1
NO_x	-- nitrogen oxide emissions
POM	-- polycyclic organic material(s)
S	-- source severity
SO_x	-- sulfur oxide emissions
TLV	-- threshold limit value
π	-- 3.14

CONVERSION FACTORS AND METRIC PREFIXES[a]

CONVERSION FACTORS

To convert from	to	Multiply by
Degree Celsius (°C)	Degree Fahrenheit	$t_F^\circ = 1.8\ t_C^\circ + 32$
Kilogram (kg)	Pound-mass (avoirdupois)	2.205
Kilometer^2 (km^2)	Mile^2	3.861×10^{-1}
Meter (m)	Foot	3.281
Meter^2 (m^2)	Foot^2	1.076×10^{1}
Meter^3 (m^3)	Foot^3	3.531×10^{1}
Meter^3	Yard^3	1.308
Metric ton	Pound-mass	2.205×10^{3}
Second (s)	Minute	1.667×10^{-2}

METRIC PREFIXES

Prefix	Symbol	Multiplication factor	Example
Kilo	k	10^3	1 kg = 1 x 10^3 grams
Centi	c	10^{-2}	1 cm = 1 x 10^{-2} meter
Milli	m	10^{-3}	1 mg = 1 x 10^{-3} gram
Micro	μ	10^{-6}	1 μg = 1 x 10^{-6} gram

[a]Metric Practice Guide. ASTM Designation E 380-74, American Society for Testing and Materials, Philadelphia, Pennsylvania, November 1974. 34 pp.

SECTION 1

INTRODUCTION

Waste material separated from coal is piled into banks either near the mine or near preparation plants, and is referred to as coal refuse, gob, culm, or reject material. Coal refuse can also be disposed of in settling ponds or used as a fill material for building impoundments for settling ponds. Indiscriminate dumping and/or poor maintenance of refuse may result in spontaneous combustion and burning of refuse piles and impoundments. Spontaneous combustion of coal is also associated with fires in abandoned mines and outcrops.

An investigation of atmospheric emissions from burning coal refuse piles, abandoned mines, and outcrops was conducted to provide a better understanding of the distribution and characteristics of emissions than had been previously available in the literature. Data collection emphasized the accumulation of sufficient information to permit determination of the need for developing or applying control technology.

This document contains information on the following items:

- Magnitude and composition of emissions.
- Hazard potential of emissions.
- Geographical distribution and source severity.
- State of the art and future considerations in air pollution control technology.
- Projected growth of sources and its effect on source emissions.

SECTION 2

SUMMARY

Spontaneous combustion of coal results in the burning of coal refuse piles, impoundments, abandoned mines, and outcrops. A Bureau of Mines survey shows that there are 271 burning refuse piles and impoundments and 441 burning abandoned mines and outcrops. The states of Kentucky, West Virginia, and Pennsylvania account for 63% of burning coal refuse piles and impoundments, and the states of Montana, Wyoming, Colorado, and New Mexico account for 66% of burning abandoned mines and outcrops. There are 250 x 10^6 metric tons[a] of burning refuse material. The amounts of refuse material in burning impoundments and of coal burning in abandoned mines and outcrops are unknown.

Burning of coal piles, impoundments, abandoned mines and outcrops results in emissions of various pyrolysis and combustion products such as particulates; nitrogen oxides; sulfur oxides; carbon monoxide; hydrogen sulfide; ammonia; hydrocarbons including benzene, toluene and xylene; and polycyclic organic materials (POM). Trace elements such as arsenic, boron and mercury are also emitted. Table 1 gives the emission factors for various pollutants.

TABLE 1. MASS EMISSIONS, NATIONAL BURDEN, SOURCE SEVERITY AND AFFECTED POPULATION FOR EMISSIONS FROM COAL REFUSE PILES

Pollutant	Emission factor, kg/hr per metric ton of burning refuse	Representative source emissions, kg/yr	U.S. emissions, metric tons/yr	National burden, %	Source severity	Affected population, persons
Total particulates	3.4×10^{-7}	1,600	190	0.001	0.0003	0
Nitrogen oxides	6.7×10^{-5}	3.1×10^{5}	3.4×10^{4}	0.16	0.18	1,000
Sulfur oxides	7.4×10^{-5}	3.4×10^{5}	3.9×10^{4}	0.14	0.05	0
Hydrocarbon as CH_4 equivalents	6.7×10^{-5}	3.1×10^{5}	3.4×10^{4}	0.14	0.15	180
Carbon monoxide	8.7×10^{-3}	4.1×10^{7}	4.5×10^{6}	4.9	0.09	0
Hydrogen sulfide	3.0×10^{-4}	1.4×10^{6}	1.6×10^{5}		1.5	6,700
Ammonia	4.3×10^{-5}	2.0×10^{5}	2.3×10^{4}		0.0009	0
Mercury	4.6×10^{-9}	21			0.01	0
Polycyclic organic materials	1.3×10^{-8}	59			0.92	3,900

Note. —Blanks indicate that values are negligible.

[a] 1 metric ton = 10^6 grams; conversion factors and metric system prefixes are presented in the prefatory material.

A representative burning coal pile/impoundment is defined as one with a volume of 1.7×10^6 m^3 and an average *in situ* dry density of 1.5 metric tons/m^3, with about 21% of it burning. The representative pile/impoundment is a byproduct of bituminous coal mining operations. A representative abandoned mine/outcrop is not defined due to lack of data. Table 1 also shows the source severity and affected population for various pollutants emitted from representative sources. The source severity is defined as the ratio of the time-averaged maximum ground level concentration of an emission species to the hazard factor for the species. The hazard factor is a value equal to the primary ambient air quality standard for criteria pollutants[a] or a reduced threshold limit value for noncriteria pollutants. The affected population is defined as the number of persons around a representative source who are exposed to concentrations of airborne materials which result in a source severity greater than 0.1.

Emissions from fires in coal refuse piles, abandoned mines, and outcrops contribute 0.001% of the particulates, 0.16% of the nitrogen oxides, 0.14% of the sulfur oxides, 0.14% of the hydrocarbons, and 4.9% of the carbon monoxide emitted nationally. The following states have emissions of at least one criteria pollutant due to burning piles, abandoned mines, and outcrops that exceed 1% of state total emissions for that pollutant: Alabama, Colorado, Illinois, Kentucky, Pennsylvania, Utah, Virginia, Washington, and West Virginia. The national burdens for various pollutants are also listed in Table 1.

Various practices have been developed to control emissions from burning coal refuse piles, abandoned mines and outcrops. The main principle of control is to cut off the source of oxygen. Control practices such as blanketing the pile with incombustible material, quenching the burning pile with water, filling underground mines with fly ash slurry, isolating the burning pile/mine/outcrop, and building fire barriers have been employed.

[a]Criteria pollutants are particulates, carbon monoxide, nitrogen oxides, sulfur oxides, and hydrocarbons.

SECTION 3

SOURCE DESCRIPTION

SOURCE DEFINITIONS

Coal Refuse Piles and Impoundments

Coal as it comes from the mine contains various amounts of impurities such as slate, shale, bone, calcite, gypsum, clay and pyrite which are removed prior to marketing. These impurities are referred to as coal refuse, culm, gob, or reject material. Actual composition of a refuse pile depends upon the preparation procedures, coal composition, and mining operations.

Coarse refuse, i.e., greater than 595 μm (greater than 28 mesh), is piled into banks either near the mine or near the preparation plants. Coal refuse is deposited by dump trucks, mine cars, conveyors or aerial trams. Indiscriminate dumping of refuse and poor maintenance of refuse piles may result in: 1) refuse being piled directly on trees and shrubs; 2) the creation of voids in the pile that allow free circulation of air; 3) piles having very steep slopes, i.e., greater than 50%, 4) extraneous refuse such as used mine timbers, household neighborhood refuse, brattice cloth, oily rags, etc., being deposited on the pile; and 5) deposition of refuse near mine openings or residential areas, thereby increasing the chances of ignition and the hazards associated with burning piles (1).

Fine refuse, i.e., less than 595 μm (less than 28 mesh), is often pumped to impoundments or settling ponds as slurry and allowed to settle, leaving clear water for recycling. The refuse may also be separated in filters or clarifiers. The impoundments are usually built with coal refuse as it is the cheapest fill material available, but some impoundments are made of concrete. The settled material is periodically removed and dumped on the refuse pile.

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(1) Sussman, V. H., and J. J. Mulhern. Air Pollution from Coal Refuse Disposal Areas. Journal of the Air Pollution Control Association, 14(7):279-284, 1964.

Abandoned Mines

Abandoned coal mines are inactive, depleted underground coal mines resulting from extracting the readily available coal. Some residual coal may be left as pillars to support the overburden.

Outcrops

A coal outcrop is a coal bed that has come out to the surface due to a combination of its flatness and the hilly topography.

SPONTANEOUS COMBUSTION OF COAL AND COAL REFUSE

Coal Refuse

Spontaneous heating of coal and coal refuse piles is mainly an oxidation phenomenon involving coal, associated pyrite and impure coal substances. It is also influenced by the presence of moisture.

The oxidation of carbonaceous and pyritic material in the coal refuse is an exothermic reaction. The temperature of a coal refuse pile or portions of it will increase if the amount of circulating air is sufficient to cause oxidation but insufficient to allow for dissipation of heat. The temperature of the refuse then increases until ignition temperature is reached (1).

Experimental evidence has shown that the heat of wetting of coal is more than the heat of oxidation of coal. Thus, the presence of moisture in the air accelerates the self-heating process in coal refuse piles (2).

Coal containing a high percentage of textural moisture (i.e., moisture retained in the pores of coal which does not cause it to feel wet) loses the moisture on exposure to air, thus offering the large surface of the pores for oxygen adsorption (3).

Oxidation of pyritic impurities in coal refuse piles is another supplementary factor which enhances coal combustion. Oxidation of pyrite is a highly exothermic reaction that increases the temperature of the coal and thus increases its rate of oxidation. The oxidation process requires the presence of moisture as shown by the following equations:

---

(2) Guney, M., D. J. Hodges, and F. B. Hinsley. An Investigation of the Spontaneous Heating of Coal and Gaseous Products. Mining Engineer (London), 129(110):67-84, 1969.

(3) Haslam, R. T., and R. P. Russell. Fuels and Their Combustion. McGraw-Hill Book Company, New York, New York, 1926. 809 pp.

$$FeS_2 + 3O_2 \rightarrow FeSO_4 + SO_2 \quad (1)$$

$$2FeS_2 + 2H_2O + 7O_2 \rightarrow 2FeSO_4 + 2H_2SO_4 - 2.69 \text{ MJ/g-mole} \quad (2)$$

Other factors which affect combustion of coal or coal refuse are:

- External sources of heat such as steam pipes, sun's rays, etc.
- Coal particle size--small size exposes greater total surface area to oxidation, permitting more rapid oxidation, but fine coal particles, through denser packing, can also reduce the flow of air and thus decrease the rate of oxidation.

Coal refuse piles are considered to be burning if they exhibit the following indicators of burning:

- Presence of smoke, fumes, flames, thermal waves above pile, fire glow, or
- An internal temperature of 93°C and a history of increasing temperature.

Historically the U.S. Bureau of Mines has identified burning coal refuse piles through observation of smoke, flames, fire glow, fumes, or thermal waves above the pile. However, a refuse pile that is not presenting the above evidence may also be burning internally, or be at a stage of thermal activity which will give rise to pollutants, or cause the pile to spontaneously ignite at some future date. The Pennsylvania Department of Environmental Resources has conducted limited infrared aerial surveys of refuse piles which do not exhibit outward signs of combustion but for which thermal activity is suspected. It is their experience that coal refuse piles exhibiting an increasing internal temperature in excess of 93°C require extinguishment for protection of the public health (personal communication with P. Marcus, U.S. Bureau of Mines, Division of Environment, Washington, D.C., 8 July 1975).

Abandoned Mines and Outcrops

Spontaneous combustion of coal in abandoned mines and outcrops is also attributed to oxidation phenomena involving coal, moisture and pyritic impurities. Other factors which influence coal combustion are:

- Rank of coal--a low-rank coal such as subbitiuminous or high-volatile bituminous coal will be more susceptible than a high-rank coal such as low-volatile bituminous or anthracite coal (4). This is because the low-ranked coals contain a greater amount of moisture and pyritic impurities, which enhance spontaneous combustion of coal.

(4) Feng, K. K., R. N. Chakravorty, and T. S. Cochrane. Spontaneous Combustion - A Coal Mining Hazard. CIM Bulletin, 66(738):75-84, 1973.

- The presence of faults in coal seams helps in the leakage of air because of weak or fractured strata conditions (4).
- Strata temperature increases with depth; thus, oxidation rate will increase with depth, making the seam more vulnerable to spontaneous combustion (4).

Outcrops and abandoned coal mines are considered to be burning if they show the following burning indicators:

- Presence of smoke, fumes, flames above outcrop or emitted from mine opening, or
- Thermal activity above an as yet undefined threshold value.

PRODUCTS OF COMBUSTION

Gases

As the temperature of a coal mass increases through self or external heating, pyrolysis and carbonization occur and volatile matter is released. If there is sufficient oxygen and if the temperature is high enough, the volatile matter, and solid residue may ignite and burn; if not, the volatiles are released into the atmosphere. The volatile matter, in general, consists of hydrocarbons, hydrogen, and carbon monoxide. The products of complete combustion are carbon dioxide and water vapor. Oxides of sulfur are emitted due to oxidation of pyrite materials in coal.

Other gases which have been identified in emissions from coal combustion are: hydrogen sulfide; carbon disulfide; n-hydrocarbons (methane, ethane, propane, butane); olefins (propylene, butylene); and aromatics (phenol, benzene, toluene, xylene) (5). These gases are formed due to thermal cracking or condensation of the volatile matter.

Particulates

Particulate emissions from refuse piles result from wind erosion and from entrainment of unburned coal and fly ash in the gaseous products of oxidation and combustion. However, the major contributors to particulate emissions are products of incomplete combustion. If the ratio of oxygen to volatile matter in coal is too low, the hydrocarbon molecule is cracked to carbon and hydrogen, with hydrogen burning to water and carbon suspended as smoke.

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(5) Flann, R. C., and G. M. Lukaszewski. The Prevention and Control of Burning in Waste Coal Dumps. Proceedings of the Australasian Institute of Mining and Metallurgy, 238:11-29, 1971.

The volatile matter can also condense into high molecular weight liquid or solid aerosols.

No studies have been conducted to quantify the magnitude and composition of the particulate emissions. However, data are available in the published literature on the hazardous constituents of the particulate emissions such as arsenic, boron and POM including benzo(a)pyrene (6, 7).

FACTORS AFFECTING EMISSIONS

Coal Refuse Piles

The following factors affect emissions from coal refuse piles:

- Oxygen concentration in the pile, which is dependent on:
  - Particle size distribution of pile.
  - Type of surface of pile.
  - Wind speed.
- Type of coal.
- Relative humidity (of atmospheric air).
- Moisture content of coal.
- Type (mix) of refuse.
- Temperature.

Abandoned Mines and Outcrops

The following factors affect emissions from abandoned mines and outcrops:

- Oxygen concentration, which is affected by:
  - Air leakage through natural faults and cracks in coal seams.
  - Air leakage through cracks or holes caused by subsidence.
- Type of coal.

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(6) Duncan, L. J., E. L. Keitz, and E. P. Krajeski. Selected Characteristics of Hazardous Pollutant Emissions, Volume II. MTR-6401, Mitre Corporation, McLean, Virginia, May 1973. 331 pp.

(7) Particulate Polycyclic Organic Matter. National Academy of Sciences, Washington, D.C., 1972. 361 pp.

- Depth of stratum.
- Relative humidity (of atmospheric air).
- Moisture content of coal.
- Temperature.

GEOGRAPHICAL DISTRIBUTION

There were 206 burning coal refuse piles and 65 burning impoundments in 13 coal producing states in 1972. The states of West Virginia, Pennsylvania, Virginia, and Kentucky accounted for 84% of the burning refuse piles, and West Virginia and Pennsylvania accounted for 87% of the burning impoundments (8).

No recent data are available on the tonnage of waste material contained in coal refuse piles and impoundments. However, a 1968 survey by the U.S. Bureau of Mines showed that about 250×10^6 metric tons of refuse material were contained in coal refuse piles in the United States at that time (9).

In January 1976 there were 441 fires in abandoned coal mines and outcrops in 18 coal producing states. The states of Montana, Wyoming, Colorado, and New Mexico accounted for about 66% of these fires (personal communications with D. L. Donner, U.S. Bureau of Mines, Denver Mining Research Center, 10 December 1975, and with M. O. Magnuson, U.S. Bureau of Mines, Pittsburgh Mining and Safety Research Center, 6 January 1976). No attempts have yet been made to quantify the tonnage involved in burning abandoned mines and outcrops.

Table 2 shows the number of burning refuse piles, impoundments, abandoned mines and outcrops in the United States, by state.

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(8) List of Coal Waste Banks. U.S. Department of the Interior, Washington, D.C., June 15, 1972. 288 pp.

(9) McNay, L. M. Coal Refuse Fires, An Environmental Hazard. Bureau of Mines IC-8515, U.S. Department of the Interior, Washington, D.C., 1971. 50 pp.

TABLE 2. NUMBER OF BURNING COAL REFUSE PILES, IMPOUNDMENTS, ABANDONED MINES, AND OUTCROPS IN THE UNITED STATES, BY STATE (8)[a]

State	Refuse piles[b]		Impoundments[b]		Abandoned mines and outcrops[d]
	Active	Inactive[c]	Active	Inactive[c]	
Alabama	7	1	4	12	
Alaska	1	4	1		7
Arizona					38
Arkansas	1				
Colorado	8	37			66
Illinois	0	9	0	2	
Indiana	0	6			
Kentucky	28	90	1	94	6
Maryland	1				2
Montana	2	12			105
New Mexico	4	16			39
North Dakota	0	9			18
Ohio	7	2	0	3	7
Oklahoma					1
Oregon	0	1			
Pennsylvania	37	123	16	43	37
South Dakota					3
Tennessee	1	3	0	4	
Texas					1
Utah	0	7	0	2	28
Virginia	30	76	2	20	1
Washington	0	4	0	1	2
West Virginia	79	68	41	42	8
Wyoming	0	19	0	2	88
TOTAL	206	467	65	225	441

[a]Personal communications with D. L. Donner and M. O. Magnuson.

[b]1972 data.

[c]Indicates not presently burning but could burn.

[d]1975 data.

Note.—Blank areas indicate not reported.

SECTION 4

EMISSIONS

SELECTED POLLUTANTS

Fires in coal refuse piles, abandoned mines, and outcrops result in emissions of particulates, hydrocarbons, carbon monoxide, nitrogen oxides, sulfur oxides, and polycyclic organic matter. In addition, trace elements such as mercury, arsenic, boron, titanium, chromium, lead, copper, and manganese are also emitted. However, the trace element concentrations are too low to affect ambient air quality significantly (see Appendix A).

Table 3 lists the health effects, atmospheric stabilities and ambient air quality standards of emitted criteria pollutants. Table 4 lists the various polycyclic organic materials (POM) emitted from coal refuse fires and also indicates their carcinogenicity. For the purpose of calculations in this document, a threshold limit value (TLV®) of 1 $\mu g/m^3$ was used for all POM's irrespective of their carcinogenic characteristics.

MASS EMISSIONS AND EMISSION FACTORS

Coal Refuse Piles and Impoundments

Calculation of the source severity and the state and national emission burdens necessitates a knowledge of the emission rate for every source in the United States. Conducting emission measurements on a source-by-source basis was impractical due to the large number of individual sources and the diversity of source types. A method was therefore developed to derive an emission factor as kilograms of pollutant emitted per hour from a cubic meter or a metric ton of burning coal refuse. The emission rate for each of the source types was then estimated as the product of the emission factor and the quantity of burning coal refuse.

A detailed literature survey was conducted to obtained published data on coal refuse fire emissions as well as their composition. However, no quantitative date were obtained, and a preliminary sampling of emissions from a burning coal refuse pile was conducted (see Appendix A for sampling details and results). The emission factors determined from the preliminary sampling results for criteria and noncriteria pollutants are displayed in Table 5

TABLE 3. CHARACTERISTICS OF CRITERIA POLLUTANTS EMITTED FROM COAL REFUSE, ABANDONED MINE AND OUTCROP FIRES

Compound	Ambient air quality standard		Health effects	Atmospheric stability
	Primary	Secondary		
Particulates	260 $\mu g/m^3$ (for 24 hr).	150 $\mu g/m^3$ (for 24 hr).	Depends on the composition.	Stable.
Nitrogen oxides	100 $\mu g/m^3$ (annual arithmetic mean).	Same as primary.	Dangerous irritant to lungs.	Contributes to photochemical smog.
Carbon monoxide	10 mg/m^3 (8-hr value not to be exceeded more than once a year).	Same as primary.	Asphyxiating gas.	Stable.
Hydrocarbons	160 $\mu g/m^3$ (3 hr, from 6 a.m. to 9 a.m.).[a]	Same as primary.	Simple asphyxiants.	Contributes to photochemical smog.
Sulfur oxides	80 $\mu g/m^3$ (annual arithmetic mean)	Same as primary.	Dangerous irritant. Synergistic effects with particulates unknown.	Possible formation of sulfates.

[a]There is no primary ambient air quality standard for hydrocarbons. The value of 160 $\mu g/m^3$ used for hydrocarbons in this report is a recommended guideline for meeting the primary ambient air quality standard for photochemical oxidants.

TABLE 4. POLYCYCLIC ORGANIC MATERIALS EMITTED FROM COAL REFUSE FIRES, AND THEIR CARCINOGENICITY

POM	Carcinogenicity (7)
Dibenzothiophene	Unknown
Anthracene/phenanthrene	Not carcinogenic
Methylanthracenes/phenanthrenes	Unknown
9-Methylanthracene	Unknown
Fluoranthene	Not carcinogenic
Pyrene	Not carcinogenic
Benzo(c)phenanthrene	Strongly carcinogenic
Chrysene/benz(a)anthracene	Carcinogenic
Dimethylbenzanthracenes (isomers)	Strongly carcinogenic
Benzo(k or b)fluoranthene	Not carcinogenic
Benzo(a)pyrene/benzo(e)pyrene/perylene	Strongly carcinogenic
3-Methylcholanthrene	Unknown
Dibenz(a,h or a,c)anthracene	Strongly carcinogenic
Indeno(1,2,3-c,d)pyrene	Unknown
7H-Dibenzo(c,g)carbazole	Strongly carcinogenic
Dibenzo(a,h or a,i)pyrene	Strongly carcinogenic

TABLE 5. EMISSION FACTORS FOR COAL REFUSE FIRE EMISSIONS

Pollutant	Emission factors: kg/hr per m^3 of burning coal refuse	Emission factors: kg/hr per metric ton of burning coal refuse
Criteria pollutants:		
Total particulates	5.1×10^{-7}	3.4×10^{-7}
Respirable particulates	1.3×10^{-8}	8.7×10^{-9}
Nitrogen oxides	1.0×10^{-4}	6.7×10^{-5}
Sulfur dioxide	1.1×10^{-4}	7.4×10^{-5}
Sulfur trioxide	2.7×10^{-7}	1.8×10^{-7}
Hydrocarbons	1.0×10^{-4}	6.7×10^{-5}
Carbon monoxide	1.3×10^{-2}	8.7×10^{-3}
Noncriteria pollutants:		
Ammonia	6.5×10^{-5}	4.3×10^{-5}
Hydrogen sulfide	4.5×10^{-4}	3.0×10^{-4}
Mercury	6.8×10^{-9}	4.6×10^{-9}
Polycyclic organic materials	1.9×10^{-8}	1.3×10^{-8}

as kilograms/hour per cubic meter of burning refuse. In tests conducted by the U.S. Bureau of Mines the average *in situ* density of coal piles was found to be 1.5 metric tons/m^3 (10). Using this density value the emission factors were also calculated as kilograms/hour per metric ton of burning refuse and included in Table 5.

Emission factors for polycyclic organic materials refer only to those emitted as particulates, not vapors.

Confidence levels cannot be quoted for the emission factors shown in Table 5 due to the limited nature of the preliminary sampling. Detailed sampling of emissions involving a number of sources is necessary to establish such levels.

(10) Busch, R. A., R. R. Backer, and L. A. Atkins. Physical Property Data on Coal Waste Embankment Materials. Bureau of Mines RI-7964, U.S. Department of the Interior, Washington, D.C., 1974. 142 pp.

Abandoned Mines and Outcrops

An emission factor approach cannot be used to estimate emissions from fires in abandoned mined and outcrops as it is impossible to estimate or measure the volume/weight of burning coal in an abandoned mine or outcrop. A number of sources across the United States would have to be sampled and the mean emission rate determined for various pollutants. Statewide and nationwide emissions could then be estimated as the product of the mean emission rate and the corresponding number of sources in each state. This is not within the scope of this report.

DEFINITION OF REPRESENTATIVE SOURCE

A representative coal refuse pile/impoundment was defined so as to determine the source severity and affected population described in Section 4. This representative source has a volume of 1.7×10^6 m^3 and an average *in situ* dry density of 1.5 metric tons/m^3 with about 21% of it burning (8, 9). The representative pile/impoundment is defined as a byproduct of bituminous coal mining operations.

SOURCE SEVERITY AND AFFECTED POPULATION

The source severity is defined as the ratio of the time-averaged maximum ground level concentration of an emission species from the representative source to the hazard factor for the species (11). The hazard factor is a value equal to the primary ambient air quality standard for criteria pollutants or a reduced TLV for noncriteria pollutants. The affected population is defined as the number of persons around a representative source who are exposed to concentrations of airborne materials which result in a source severity greater than 0.1.

Source severities due to and the population affected by emissions of criteria and noncriteria pollutants from coal refuse fires are shown in Table 6. Sample calculations for source severity and affected population are provided in Appendix B. The representative distance is the distance from the source to the plant boundaries. This is taken as 1.6 km.

The representative population density is defined as the average population density around a burning coal refuse source. This value is 46 persons/km^2 and is based on the results of a survey conducted by the Bureau of Mines on coal refuse piles (9).

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(11) Blackwood, T. R., and R. A. Wachter. Source Assessment: Coal Storage Piles. Contract 68-02-1874, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, July 1977. 96 pp.

TABLE 6. SOURCE SEVERITY AND AFFECTED POPULATION FOR EMISSIONS FROM COAL REFUSE FIRES

Type of pollutant	Source severity	Affected population
Total particulates	3×10^{-4}	0
Nitrogen oxides	0.18	1,000
Sulfur oxides	0.05	0
Hydrocarbons	0.15	180
Carbon monoxide	0.09	0
Polycyclic organic materials	0.92	3,900
Hydrogen sulfide	1.5	6,700
Ammonia	9.0×10^{-4}	0
Mercury	0.01	0

STATE AND NATIONAL EMISSION BURDENS

Tables 7 and 8 display the state and national emission burdens due to coal refuse burning. The individual state emissions are the product of the emission factor given in Table 5 and the total quantity of coal refuse for that state. It is assumed that about 21% of the pile is burning.

TABLE 7. MASS EMISSIONS FROM COAL REFUSE FIRES

State	Amount of coal refuse, 10^3 m^3	Particulate emissions, metric tons/yr	Sulfur oxide emissions, metric tons/yr	Nitrogen oxide emissions, metric tons/yr	Total hydrocarbon emissions, metric tons/yr	Carbon monoxide emissions, metric tons/yr
Alabama	11,000	10	2,200	2,000	2,000	260,000
Colorado	12,000	11	2,400	2,200	2,200	290,000
Illinois	5,400	5.1	1,100	990	990	130,000
Kentucky	1,600	15	320	290	290	38,000
Maryland	23	0.02	5	4	4	550
Montana	230	0.22	47	42	42	5,500
Ohio	1,400	1.3	280	260	260	33,000
Pennsylvania	84,000[a]	79	17,000	15,000	15,000	2,000,000
Utah	2,100	2	420	390	390	50,000
Virginia	2,800	2.6	570	520	520	67,000
Washington	2,300	2.2	470	420	420	55,000
West Virginia	67,000	63	14,000	12,000	12,000	1,600,000
TOTAL[b]	190,000	190	39,000	34,000	34,000	4,500,000

[a] Includes 4,200 m^3 of anthracite refuse.

[b] Totals may not add up to figures shown due to independent rounding.

TABLE 8. STATE AND NATIONAL EMISSION BURDENS FROM COAL REFUSE FIRES
(percent)

State	Particulates	Sulfur oxides	Nitrogen oxides	Total hydrocarbons	Carbon monoxide
Alabama		0.25	0.5	0.31	14
Colorado	0.01	4.9	1.5	1.1	33
Illinois		0.05	0.1	0.05	2.0
Kentucky		0.03	0.07	0.09	3.2
Maryland					0.04
Montana		0.01	0.03	0.02	0.90
Ohio		0.01	0.02	0.02	0.63
Oklahoma					0.03
Pennsylvania		0.58	0.50	1.7	54
Utah		0.27	0.05	0.40	12
Virginia		0.13	0.02	0.14	4.3
Washington		0.17	0.22	0.12	3.3
West Virginia	0.03	2.1	5.2	10.0	3.2
TOTAL	0.001	0.14	0.16	0.14	4.9

Note.—Blanks indicate amounts are negligible.

SECTION 5

CONTROL TECHNOLOGY

STATE OF THE ART

Coal Refuse Fires

Discussed below are several methods employed by state and federal government agencies to control burning coal refuse piles.

Isolation--
The burning area is isolated from the remainder of the refuse pile by trenches and is quenched with water or blanketed with incombustible material.

Blanketing--
Some refuse piles are extinguished by leveling the top, then sealing it and the sides with fine, incombustible material such as fly ash, clay, quarry wastes, or acid mine drainage sludge. Heavy seals of such material are necessary in order to avoid erosion. Use of clay is limited as it cracks over hot spots, impairing the seal (12).

Grouting--
A slurry of water and finely divided incombustible material, such as pulverized limestone, fly ash, coal silt or sand, is forced into the burning pile so as to provide some cooling action and also to fill the voids to prevent air from entering the pile. The unit cost of controlling refuse pile fires using lime slurry was $\$1.46/m^3$ of refuse, based on a 1969 study by the Pennsylvania Department of Mines and Mineral Industries (13).

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(12) Corey, R. C., R. B. Engdahl, J. J. Foster, J. R. Garvey, and H. C. Rose. The Disposal of Coal Refuse. Journal of the Air Pollution Control Association, 6(2):105-110, 1956.

(13) Darkes, W. F. Final Report, Experimental Extinguishment Project No. 67A-4112D, Fails Slope Refuse Bank. Department of Mines and Mineral Industries, Commonwealth of Pennsylvania, Harrisburg, Pennsylvania, May 1970. 14 pp.

Explosives--
Many burning piles have an impenetrable, ceramic-like, clinker material surface which does not allow the penetration of slurries and water. In this case explosive charges are placed deep into the bank through horizontally drilled holes. The explosion creates fissures in the fused covering material. Water is then applied through these crevices and the quenched material is loaded out. The overall cost of fire control using this method was $\$2.86/m^3$ of material, based on a Pennsylvania Department of Mines and Mineral Industries study in 1968 (14).

Spraying--
In this method water is sprayed over the entire refuse bank. However, this is only a temporary solution as the pile reignites and burns, often with renewed vigor, once the water spray is stopped (15). This procedure also creates the problem of runoff from the refuse bank.

Accelerated Combustion and Quenching--
The burning refuse material is lifted by a dragline and dropped through air into a water-filled lagoon 15 m to 30 m below for the purpose of burning off the combustible material completely during the drop. Another dragline and bulldozers are used to remove the quenched material from the lagoon floor and compact it into a tight, dense fill material. A disadvantage with this method is the emission of particulate matter while the burning refuse is falling.

Ponding Technique--
Retaining walls are constructed around the perimeter of a refuse bank after subdividing the surface into a series of level discrete areas or "rice paddies," and each area is filled with water. Though this method has a lower cost compared to other methods, it has not proved successful. Flooding with water may cause explosions due to the formation of water gas. Further, penetration of water into the pile is poor - only about 0.6 m to 1 m deep (15).

Cooling and Dilution--
Water is sprayed on the burning pile from multiple nozzles, and the cooled refuse is mixed, by bulldozer, in a one-to-one volume

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(14) Mahinka, S. P. Final Report, Experimental Extinguishment Project No. 66A-4108D, Bellevue Baker Bank. Department of Mines and Mineral Industries, Commonwealth of Pennsylvania, Harrisburg, Pennsylvania, August 1968. 34 pp.

(15) Maneval, D. R. Recent Advances in Extinguishment of Burning Coal Refuse Banks for Air Pollution Reduction. American Chemical Society, Division of Fuel Chemistry, Preprints, 13(2):27-41, 1969.

proportion with soil and/or burned out refuse from a nearby area. The mixture is then compacted by heavy equipment (15). According to an engineering survey in White Station, Pennsylvania, this method of control was estimated to cost about $\$0.60/m^3$ of refuse in 1968 (16).

Hydraulic Jets--
Projects conducted by the U.S. Bureau of Mines and the Pennsylvania Department of Mines involved the application of "hydraulic giants" or high velocity water connons to quench the burning refuse material. The quenched material was then relayered and compacted by a dragline and bulldozer (15). The unit cost of the operation performed in 1968 was $\$0.98/m^3$ (17).

Abandoned Mines and Outcrop Fires

Abandoned mine and outcrop fires can be controlled by the various methods discussed below (18). The principle of control is to isolate the burning material and prevent air from reaching it.

Loading Out--
This method involves digging out the burning and heated material, then cooling it with water or spreading it on the ground. This method is effective if the fire is of recent origin or mild enough to be accessible.

Fire Barriers--
A barrier of incombustible material is used to confine and isolate the fire from the main body of coal. The isolated area is also surface sealed to extinguish the fire.

The barrier can be an open trench, between the fire area and the threatened area, which is backfilled with incombustible material such as earth, fly ash or granulated slag.

A plug barrier is used if the overburden is excessive, since it is impractical to excavate a trench from outcrop to outcrop

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(16) Mahinka, S. P. Final Report, Experimental Extinguishment Project No. 66A-4106D, White Station Bank. Department of Mines and Mineral Industries, Commonwealth of Pennsylvania, Harrisburg, Pennsylvania, August 1968. 27 pp.

(17) Mahinka, S. P. Final Report, Experimental Extinguishment Project No. 66A-4109D, Marvine Bank. Department of Mines and Mineral Industries, Commonwealth of Pennsylvania, Harrisburg, Pennsylvania, September 1968. 21 pp.

(18) Magnuson, M. O. Control of Fires in Abandoned Mines in the Eastern Bituminous Region of the United States. Bureau of Mines IC-8620, U.S. Department of the Interior, Washington, D.C., 1974. 53 pp.

around an abandoned mine fire. A plug barrier starts at the outcrop and terminates when the overburden depth exceeds 20 m. The plug barrier is always used in conjunction with a surface seal. A surface seal on the fire side of the plug has been observed to be effective in controlling abandoned mine fires if the overburden is in excess of about 20 m (17). Figure 1 shows top and sectional views of a plug barrier.

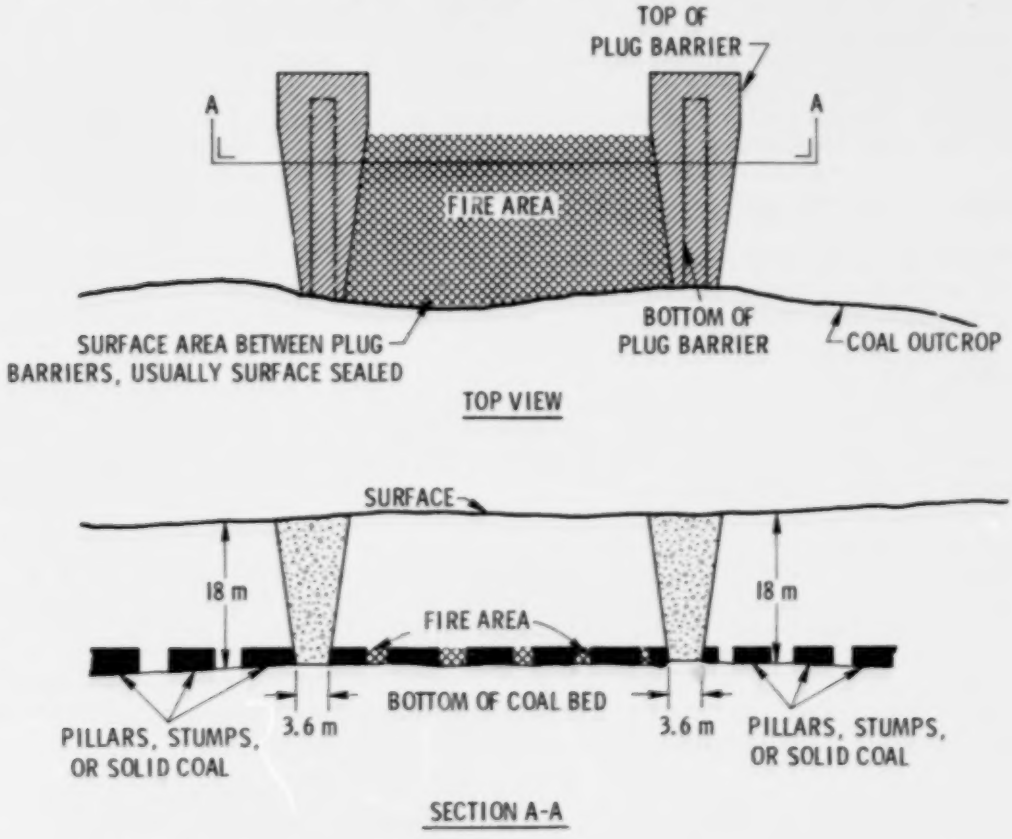

Figure 1. Top and sectional views of plug barrier (17).

Flushing--
In this method the void spaces around an underground fire are filled with water or an incombusible material such as fly ash. The incombustible material can be applied pneumatically or as a slurry.

Surface Sealing--
This technique involves closing the surface openings to prevent ventilation of the fire. The surface seal is established by plowing the surface to a depth of several meters with an angle dozer to create a blanket of pulverized earth that effectively seals the surface.

FUTURE CONSIDERATIONS

An old adage, paraphrased "Prevention is better than cure," certainly applies to the case of controlling coal refuse fires. The U.S. Department of the Interior, Mining Enforcement and Safety Administration, has recently adopted regulations that require coal companies to dispose of coal refuse in such manner as to obviate or minimize its ignition (19). Such preventive measures include compaction and blanketing of the piles with an inert material.

Other methods for the prevention of coal refuse fires are currently being studied. These include injection or coating with vermiculate and sodium bicarbonate, and the use of antioxidants (15).

Different underground mining procedures can also be employed to prevent fires (20).

Integration of Coal Waste Disposal with the Retreat Mining Method

In this approach about 40% to 60% of the coal is mined using continuous mining, or coal cutting, machines. This operation leaves "rooms" or voids, where the coal was removed, and pillars of coal which support the roof. The "rooms" or voids are then backfilled with coal refuse slurry which is allowed to solidify. Barricades constructed at the lower end and sides of the backfilled area hold back the refuse. Thus the solidified refuse supports the roof as the coal pillars are mined. This procedure is repeated until the mining has retreated to the mouth of the mine.

Integration of Coal Waste Disposal with the Longwall Mining Method

In longwall mining, the roof is held up by rows of movable hydraulic jacks while the cutting machine shears the coal from the seam. The coal refuse can be backfilled into the mined void either as a slurry or as a dry material by pneumatic backfilling. Wooden props and wire netting materials are erected parallel to the working area to hold the waste in place.

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(19) Final Environmental Statement: Regulations Governing the Disposal of Coal Mine Waste, 30 CFR, Part 77, Sections 77.215(h) through 77.217, FES 75-58. U.S. Department of the Interior, Mining Enforcement and Safety Administration, Washington, D.C., June 18, 1975.

(20) Disposing of the Coal Waste Disposal Problem. Appalachian Research and Defense Fund, Inc., Charleston, West Virginia, March 13, 1973. 98 pp.

SECTION 6

GROWTH AND NATURE OF THE INDUSTRY

As noted earlier, the U.S. Department of the Interior has recently adopted regulations that require coal companies to dispose of coal refuse in such a manner as to prevent its ignition (19). The coal companies are also required to extinguish their existing burning refuse piles. These regulations, if properly enforced, will decrease the incidence of coal refuse fires considerably. However, a Bureau of Mines study shows that there are 37 burning piles and 161 inactive coal piles whose owners are unknown (9). Table 9 presents a state-by-state listing of piles with unknown ownership.

TABLE 9. NUMBER OF COAL REFUSE PILES WITH UNKNOWN OWNERSHIP, BY STATE (9)

State	Burning piles	Inactive piles
Alaska	0	2
Colorado	2	24
Maryland	1	0
Montana	1	9
New Mexico	2	15
North Dakota	0	1
Ohio	2	0
Pennsylvania	25	92
Utah	0	3
West Virginia	4	0
Wyoming	0	15
Total	37	161

Assuming that fires in some or all coal refuse piles owned by private companies and government agencies will be completely extinguished, the number of burning piles in 1978 can vary from 0 to 198, which corresponds to a growth rate of 0% to 72%.

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APPENDIX A

PRELIMINARY SAMPLING DATA AND RESULTS

The purpose of preliminary sampling was to obtain an estimate of emissions and their composition with respect to hazardous pollutants and thus form the basis for additional testing and sampling. After the inspection of several piles, a burning coal refuse pile was chosen for preliminary sampling on the basis that its emissions were best representative of those from fires in coal refuse piles, abandoned mines or outcrops - representative with respect to the rank of coal as well as the quantity of coal refuse and fraction burning. In addition, the pile was located in an area with conditions favorable for sampling.

SOURCE DESCRIPTION

The coal refuse pile selected is a byproduct of bituminous coal mining operations. The pile has a volume of 4.3×10^6 m^3, and about 9.6×10^5 m^3 or 22% of it is burning. The pile is smoldering over a surface area of 52,000 m^2 and emitting fumes through holes with a total area of about 520 m^2. This refuse pile, active for about 12 years, has been burning for the last 10 years.

Temperatures at different points within the burning pile vary from about 80°C to about 470°C, both recorded at a depth of 1 m. Temperatures as high as 540°C were also recorded within the pile at a depth of 10 m and 1 m from the side of the pile.

SAMPLING METHODOLOGY

Two temporary stacks, each about 1.8 m high and 23 cm in diameter, were forced into the burning pile to a depth of about 5 cm to ensure a leakproof contact between the pile and the stack. Figure A-1 illustrates the setup. Emissions from the stacks were treated as point source emissions and were sampled for various hazardous pollutants. The mean value of the emission rates from the two stacks was used to estimate the overall pile emissions as follows:

$$\text{Overall pile emission rate} = (\text{mean stack emission rate}) \cdot \left(\frac{\text{surface area of pile through which fumes are emitted}}{\text{inside area of the stack}} \right)$$

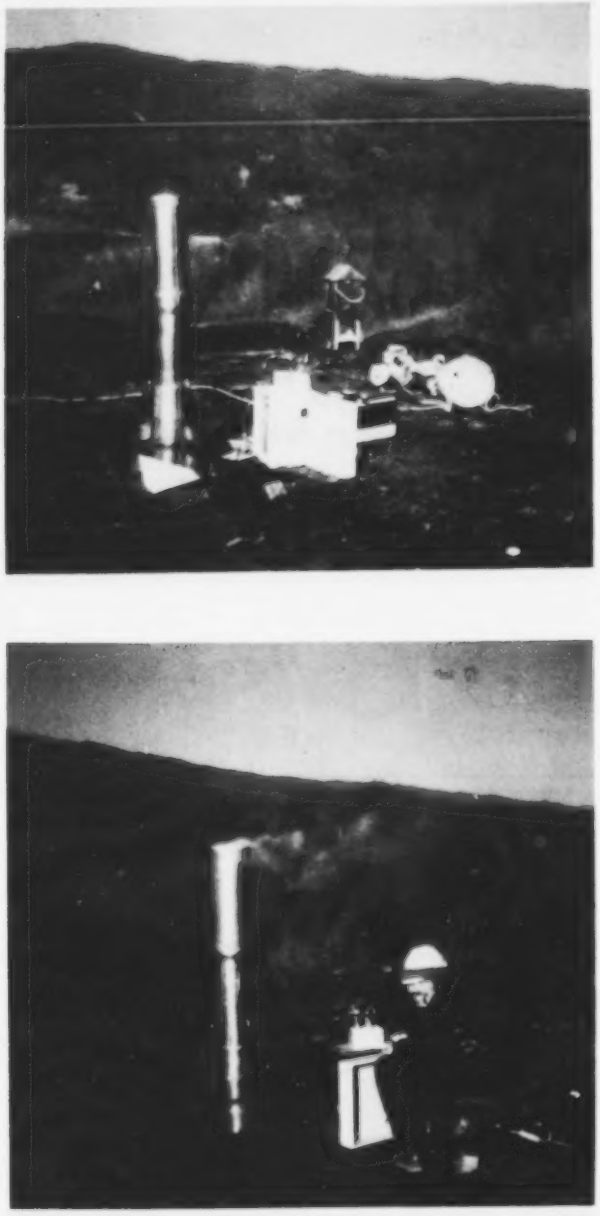

Figure A-1. Temporary stacks used for sampling emissions from coal refuse piles.

An emission factor for each pollutant was then calculated as the overall pile emission rate divided by the volume of coal refuse burning.

SAMPLING DATA AND RESULTS

Gas Flows

A unique procedure was employed to determine the gas flows. A stack was lifted off of the pile and held in that position until it cleared of fumes. The stack was then placed on the pile and the time that elapsed until the fumes came out of the stack as a visible plume was noted. The height of the stack divided by the elapsed time was taken as the average velocity of stack gases.

Table A-1 shows the gas flows and temperatures for both stacks on 2 days of testing.

TABLE A-1. GAS FLOWS AND TEMPERATURES

Sample	Average[a] gas flow, m^3/min	Average gas temperature, °C
Stack 1, day 1	0.25	31
Stack 1, day 2	0.16	32
Stack 2, day 1	1.3	61
Stack 2, day 2	0.8	54

[a]Average of four independent measurements for each stack on each day.

Total and Respirable Particulates

Two high-volume samplers were placed on the smoldering coal pile and five runs were made. A background sample was also taken with a high-volume sampler placed about 600 m upwind of the pile. Each run (except the background run) lasted only about 60 min as the filter clogged within that time due to excessive particulate loading.

Stack particulate emission rate was estimated as the product of average stack gas flow and average particulate concentration as determined by the high-volume samplers. The fraction of respirable particulates was determined by a particle count on two high-volume filters. Table A-2 displays the results of high-volume sampling.

TABLE A-2. RESULTS OF HIGH-VOLUME SAMPLING

Sample	Total particulate concentration, $\mu g/m^3$	Fraction respirable (<7 μm), %
Run 1	1,277	
Run 2	1,180	
Run 3	1,826	2.8
Run 4	1,284	2.1
Run 5[a]	215	
Background	55	
Average[a] (corrected for background)	1,337	2.5

Note.—Blanks indicate not determined.

[a]The high-volume sampler for run 5 was placed near the edge of the pile and the low value is due to frequent changes in wind direction. The reading was not considered in calculating the average value.

The average stack emission rate for total particulate was calculated as follows:

- Mean stack gas flow for day 2 = 1/2(0.16 + 0.8) = 0.48 m^3/min.
- Average total particulate concentration corrected for background concentration = 1,337 $\mu g/m^3$.
- Average stack emission rate = 1,337 x 10^{-9} kg/m^3 • 0.48 m^3/min • 60 min/hr = 38.5 x 10^{-6} kg/hr.
- Overall pile emission rate = 38.5 x 10^{-6} kg/hr • 520 $m^2/0.041$ m^2 = 0.49 kg/hr where 520 m^2 = area and 0.041 m^2 = stack area.
- Emission factor for total particulates = 0.49 kg/hr ÷ 9.6 x 10^5 m^3 = 5.1 x 10^{-7} kg/hr per m^3 of burning refuse where 9.6 x 10^5 m^3 is the amount of burning refuse.

Gaseous Emissions

Emission rates for gaseous pollutants were calculated as the product of stack gas flow and the corresponding gas concentration. Concentrations of gases were determined by using the standard

methods shown in Table A-3 (21-24). This table also displays the overall pile emission rate and emission factor for each gaseous pollutant.

TABLE A-3. SAMPLING RESULTS

Pollutant	Emission rates, kg/hr			Overall pile emission rate, kg/hr	Emission factor, kg/hr per m^3 of burning refuse	Sampling method
	Stack 1	Stack 2	Mean			
Nitrogen oxides	2.6×10^{-3}	1.3×10^{-2}	7.9×10^{-3}	100	1.0×10^{-4}	Federal Register Method 7 (21)
Sulfur dioxide	1.7×10^{-3}	1.5×10^{-2}	8.6×10^{-3}	109	1.1×10^{-4}	Federal Register Method 6 (22)
Sulfur trioxide	8.6×10^{-6}	3.1×10^{-5}	2.0×10^{-5}	0.3	2.7×10^{-7}	Federal Register Method 6 (22)
Carbon monoxide	2.2×10^{-3}	1.9	1.0	12,700	1.3×10^{-2}	Gas chromatography
Total hydrocarbons as CH_4 equivalents	2.1×10^{-3}	1.3×10^{-2}	7.6×10^{-3}	96	1.0×10^{-4}	Gas chromatography
Benzene	8.1×10^{-5}	8.2×10^{-4}	4.5×10^{-4}	6	6.0×10^{-6}	Mass spectrophotometry
Xylene	8.1×10^{-5}	8.2×10^{-4}	4.5×10^{-4}	6	6.0×10^{-6}	Mass spectrophotometry
Toluene	8.1×10^{-5}	8.2×10^{-4}	4.5×10^{-4}	6	6.0×10^{-6}	Mass spectrophotometry
Hydrogen sulfide	1.1×10^{-3}	6.7×10^{-2}	3.4×10^{-2}	430	4.5×10^{-4}	Federal Register Method 11 (23)
Ammonia	6.3×10^{-4}	9.1×10^{-3}	4.9×10^{-3}	60	6.5×10^{-5}	Sulfuric acid absorption
Mercury[a]	5.1×10^{-7}	-[b]	5.1×10^{-7}	6×10^{-3}	6.8×10^{-9}	Federal Register Method 102 (24)

[a] Questionable data; see discussion in Section 3.e of this appendix.

[b] Not determined.

Species identified include sulfur oxides, nitrogen oxides, carbon monoxide, ammonia, hydrogen sulfide and hydrocarbons. Table A-4 shows the various forms of hydrocarbons emitted from the coal refuse pile.

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(21) Environmental Protection Agency - Standards of Performance for New Stationary Sources, Method 7. Federal Register, 36(247):24891-24895, 1971.

(22) Environmental Protection Agency - Standards of Performance for New Stationary Sources, Method 6. Federal Register, 36(247):24890-24891, 1971.

(23) Environmental Protection Agency - Standards of Performance for New Stationary Sources, Method 11. Federal Register 39(47):9321-9323, 1974.

(24) Environmental Protection Agency - National Emission Standards for Hazardous Air Pollutants - Asbestos, Beryllium, and Mercury; Method 102. Federal Register, 38(66):8840-8845, 1973.

TABLE A-4. HYDROCARBONS EMITTED FROM THE BURNING COAL REFUSE PILE[a]

Hydrocarbon	Stack 1 Day 1 Run 1	Stack 2 Day 1 Run 1	Stack 2 Day 1 Run 2
Total concentration in stack gas, mg/m^3	27	104	106
Species	**Percent**		
Aliphatic hydrocarbons	20	50	30
Olefinic/alcoholic hydrocarbons	10	20	20
Dichloromethane	-[b]	-[c]	-[c]
Aromatics:			
Benzene	20	10	10
Toluene	20	10	10
Xylene(s)	20	10	10
C_3-Benzene	10	10	10
C_4-Benzene	-[b]	-[b]	-[b]
Dimethyl phenol(s)	-[b]	-[b]	-[b]
Methylnaphthalene(s)	-[b]	-[b]	-[b]
C_2-Naphthalene(s)	-[b]	-[b]	-[b]
C_3-Naphthalene(s)	-[b]	-[b]	-[b]
C_1-C_3-Styrenes	-[b]	-[c]	-[c]
Total[d]	100	100	100

[a] Figures quoted are order of magnitude estimates.

[b] Less than 5%.

[c] Not detected.

[d] Total may not add up to 100 due to independent rounding.

Concentrations of nitrogen oxides (NO_x) were determined by taking grab samples of stack gases. Sampling time for each grab sample was about 2 min and three samples were taken at each stack. NO_x concentrations at each stack varied from about 5 ppm to 160 ppm. These variations were unexplainable as no errors were attributed to analysis or sample collection. For the purpose of the following calculations, the maximum concentration values were used.

Sample Calculations, NO_x Emissions

Stack 1:

- Concentration of NO_x in the stack: 169 ppm.
- Average stack flow on day 1: 0.21 standard m^3/min.
- NO_x emission rate = 169 ppm • (30 • 0.0413 mg/standard m^3-ppm) • 0.21 standard m^3/min • 10^{-6} kg/mg • 60 min/hr = 0.0026 kg/hr.

Stack 2:

- Concentration of NO_x in the stack: 160 ppm.
- Average stack flow on day 1: 1.1 standard m^3/min.
- NO_x emission rate = 160 ppm • (30 • 0.0413 mg/standard m^3-ppm) • 1.1 standard m^3/min • 10^{-6} kg/mg • 60 min/hr = 0.013 kg/hr.
- Average for Stack 1 and Stack 2 = 0.5(0.0026 + 0.013) = 7.9×10^{-3} kg/hr.
- Overall pile emission rate = 7.9×10^{-3} kg/hr • 520 m^2/0.041 m^2 = 100 kg/hr where 520 m^2 is area through which fumes are emitted and 0.041 m^2 is the stack area.
- Emission factor is thus: 100 kg/hr ÷ 9.6×10^5 m^3 = 1.0×10^{-4} kg/hr per m^3 burning refuse.

Mercury

Federal Register Method 102 is used to estimate mercury emissions (24). This method involves absorption of mercury in iodine monochloride solution and analysis using spectrophotometry. Although a sampling time of 2 hr is recommended, the run lasted only 3 min as hydrogen sulfide (H_2S) present in the gases liberated iodine which condensed on the walls and plugged the tubing. Detailed information is not available regarding the interferences of sulfide and organic compounds. There interferences should be quantified before using this method for any future mercury sampling from coal refuse fires.

POM and Trace Elements

Particulate samples collected on high-volume sampler filters were analyzed for POM, arsenic, boron, and trace elements. The results of these analyses are presented in Tables A-5 through A-7. The POM values quoted in Table A-5 do not include those emitted in the gaseous form.

TABLE A-5. ANALYSIS OF POLYCYCLIC ORGANIC MATERIAL EMISSIONS FROM COAL REFUSE FIRES

POM	Fraction present, %	
	Range	Average
Dibenzothiophene		0.4
Anthracene/phenanthrene	13 to 26	20
Methylanthracenes/phenanthrenes	17 to 42	30
9-Methylanthracene		0.8
Fluoranthene		5
Pyrene		4.6
Benzo(c)phenanthrene		0.8
Chrysene/benz(a)anthracene	15 to 32	24
Dimethylbenzanthracenes (isomers)	3 to 20	12
Benzo(k or b)fluoranthene	0.7 to 4	2.4
Benzo(a)pyrene/benzo(e)pyrene/ perylene	0.4 to 2.6	1.5
3-Methylcholanthrene		<0.2
Dibenz(a,h or a,c)anthracene		<0.2
Indeno(1,2,3-c,d)pyrene		<0.2
7H-Dibenzo(c,g)carbazole		<0.2
Dibenzo(a,n or a,i)pyrene		<0.2
Total		100

- Average concentration of POM in stack gas: 50 $\mu g/m^3$
- Average emission rate through stack: 1.4×10^{-6} kg/hr
- Overall pile emission rate: 0.02 kg/hr
- $\therefore$ POM emission factor: $\frac{1.9 \times 10^{-8} \text{ kg/hr}}{\text{m}^3 \text{ burning refuse pile}}$

Note.—Blanks indicate no range reported.

TABLE A-6. ANALYSIS OF ARSENIC AND BORON EMISSIONS FROM COAL REFUSE FIRES (percent)

Element	Sample 1	Sample 2
Arsenic		0.0003
Boron	0.2	0.1

Note.—Blank indicates not detected.

TABLE A-7. ANALYSIS OF TRACE ELEMENT EMISSIONS FROM COAL REFUSE FIRES (percent)

Element	Sample 1	Sample 2
Silicon	Major (20)[a]	Major (30)[a]
Iron	0.3	1.0
Manganese	<0.004	<0.005
Magnesium	0.03	0.01
Aluminum	0.3	1.0
Calcium	0.1	0.5
Copper	0.001	0.5
Sodium	0.004	0.01
Titanium	0.008	0.01
Lead		<0.005
Tin		0.005
Chromium		0.01
Vanadium		<0.005

Note.—Blanks indicate not detected.

[a]Figure in parentheses is a semi-quantitative estimate.

APPENDIX B

SAMPLE CALCULATIONS OF SOURCE SEVERITY AND AFFECTED POPULATION

SOURCE SEVERITY

The source severity, S, is defined as the ratio of the time-averaged maximum ground level concentration of an emission specie to the hazard factor. The hazard factor is equal to the primary ambient air quality standard for criteria[a] pollutants or to a reduced TLV (i.e., TLV x 8/24 x 1/100) for noncriteria pollutants. The time-averaged maximum ground level concentration is related to the mass emission rate, Q (in g/s), of a pollutant and to the height of emission release, and it is determined over a specific time period. For open sources, the effective height of emissions is related to the representative distance, D, from the source to the plant boundary. For a representative burning coal refuse pile, D was taken as 1,600 m.

Using the above approach, the equations shown in Table B-1 were used to determine the severity of pollutants from a representative burning coal refuse pile (11).

TABLE B-1. POLLUTANT SEVERITY EQUATIONS (11)

Pollutant	Severity equation	
Particulate	$S = \frac{4{,}020\ Q}{D^{1.81}}$	(B-1)
Sulfur oxides	$S = \frac{2{,}870\ Q}{D^{1.81}}$	(B-2)
Nitrogen oxides	$S = \frac{22{,}200\ Q}{D^{1.90}}$	(B-3)
Hydrocarbon	$S = \frac{9{,}340\ Q}{D^{1.81}}$	(B-4)
Carbon monoxide	$S = \frac{44.8\ Q}{D^{1.81}}$	(B-5)
Noncriteria pollutant	$S = \frac{316\ Q}{TLV \cdot D^{1.81}}$	(B-6)

[a]There is no primary ambient air quality standard for hydrocarbons. The value of 160 $\mu g/m^3$ used for hydrocarbons in this report is a recommended guideline for meeting the primary ambient air quality standard for photochemical oxidants.

The method used to determine the values of S for criteria and noncriteria emissions from a representative pile is illustrated in the following sample calculations for a 1.7×10^6 m^3 pile, with 21% of the pile burning:

For NO_x:

Emission rate = 1.0×10^{-4} kg/hr per m^3 burning refuse (Table 5)

$$\therefore Q = \frac{1.0 \times 10^{-4} \text{ kg/hr}}{m^3} \cdot 1.7 \times 10^6 \text{ } m^3 \cdot 0.21 \cdot 1{,}000 \text{ g/kg}$$

$$\div 3{,}600 \text{ s/hr} = 9.9 \text{ g/s}$$

$$S = \frac{22{,}200\ Q}{D^{1.90}} = \frac{22{,}200 \cdot 9.9}{1{,}600^{1.90}} = 0.18$$

For H_2S:

Emission rate = 4.5×10^{-4} kg/hr per m^3 burning refuse (Table 5)

$$\therefore Q = \frac{4.5 \times 10^{-4} \text{ kg/hr}}{m^3} \cdot 1.7 \times 10^6 \text{ } m^3 \cdot 0.21 \cdot 1{,}000 \text{ g/kg}$$

$$\div 3{,}600 \text{ s/hr} = 45 \text{ g/s}$$

The threshold limit value for H_2S is 15 mg/m^3 (25).

$$S = \frac{316 \cdot 45}{1{,}600^{1.814} \cdot 15 \times 10^{-3}} = 1.5$$

AFFECTED POPULATION

The affected population designates the average number of persons living in the area beyond the plant boundary and exposed to high concentrations of a given emission from a source. The affected population thus resides in an annular area whose inside diameter is the representative distance to the plant boundary (taken as 1.6 km in this study) and whose outside diameter is the distance corresponding to a source severity of 0.1 (i.e., $D_S = 0.1$). $D_{S = 0.1}$ is calculated by use of a rearranged severity equation.

(25) TLVs® Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1975. American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio, 1975. 97 pp.

For H_2S:

$$D_{S = 0.1} = \left(\frac{316\ Q}{TLV \times 0.1}\right)^{1/1.814}$$

$$= \left(\frac{316 \cdot 45}{15 \times 10^{-3} \cdot 0.1}\right)^{1/1.814} = 7 \text{ km}$$

Hence, the affected area = $\pi(7^2 - 1.6^2) = 147$ km^2. The affected population is equal to the product of the affected area and the representative population density, i.e., affected population = 147 km^2 • 46 persons/km^2 = 6,700 persons.

The population affected by other pollutants above a severity of 0.1 is calculated in a similar manner. For NO_x, hydrocarbons and polycyclic organic materials the affected populations to a severity of 0.1 are 1,000, 180 and 3,900, respectively.

GLOSSARY

affected population: Number of persons exposed to concentrations of airborne materials which result in a source severity greater than 0.1.

carcinogen: Chemical substance which causes cancer in animals or man.

criteria pollutants: Emission species for which ambient air quality standards have been established; these include particulates, sulfur oxides, nitrogen oxides, carbon monoxide, and nonmethane hydrocarbons.

emission burden: Ratio of the total annual emissions of a pollutant from a specific source to the total annual state or national emissions of that pollutant.

emission factor: Weight of material emitted to the atmosphere per hour from a unit volume or unit weight of burning material.

hazard factor: Value equal to the primary ambient air quality standard for criteria pollutants or to a reduced TLV (i.e., TLV • 8/24 • 1/100) for noncriteria pollutants.

noncriteria pollutants: Emission species for which no ambient air quality standards have been established.

representative source: Source whose operational characteristics and emission parameters are representative of burning coal piles, impoundments, abandoned mines, or outcrops.

source severity: Ratio of the maximum mean ground level concentration of an emission species to the hazard factor for the species.

threshold limit value: Concentration of an airborne contaminant to which workers may be exposed repeatedly, day after day, without adverse effect.